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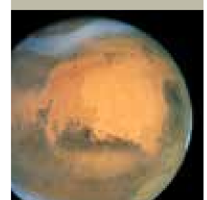

NESC tech bulletin

Damage Tolerance Life Issues in COPVs with Thin Liners

During composite overwrapped pressure vessel (COPV) qualification, damage tolerance life analysis and/or tests may not adequately address crack growth for COPVs with thin liners, and additional qualification tests beyond those in current requirements documents may be needed to quantify crack growth.

Background

Damage tolerance life (safe-life) is a fracture control approach that assumes the existence of cracks of a size that can be reliably detected by an established nondestructive evaluation (NDE) method used to inspect the COPV liner prior to service. The intent of damage tolerance life is to demonstrate that cracks at or below this size will not grow to a depth equal to the thickness of the liner (leak) or to a length that is predicted to become unstable. ANSI/AIAA S-081A1 requires that metallic COPV liners possess adequate damage tolerance life that is demonstrated by analysis or test. Details on testing and analysis are specified in S-081A.[1]

Typical spherical COPV

Issue

Many COPVs are designed with a liner that responds elastically for all pressure and combined load conditions after autofrettage. For these elastically responding liners, S-081A allows demonstration of damage tolerance life based on linear elastic fracture mechanics (LEFM).

However, the use of LEFM methods may not be appropriate if the liner is relatively thin compared to the inspectable crack depth (for example, a detectable crack depth of 0.025 inch in a liner that is only 0.04-inch thick, resulting in a ligament that is 0.015 inch). The crack growth rate through the ligament may be faster than that predicted by LEFM for two reasons:

- **Plasticity:** Even though far-field analysis shows that thin liners are responding elastically, local plasticity in the ligament must be considered. LEFM assumes that the crack-tip plastic zone is small relative to the size of the crack. Regions of local yielding (remaining ligament or local stress concentrations) adjacent to cracks may create plasticity that renders LEFM analysis inappropriate. For example, liner embossing (plastically straining the liner into the overwrap during autofrettage) could lead to highly localized strain concentrations, affecting the growth of cracks in the remaining ligament.

- **Microstructure:** When the remaining ligament is relatively small, the ligament thickness may be on the same order as microstructural features, such as grain size. The use of crack growth rate data obtained from standardized tests (such as that supplied in NASGRO) may not be representative of crack growth in the ligament. Instead, tests based on ASTM Standard E-647 (Appendix X3) guidelines that address the measurement of small fatigue crack growth rates may be more appropriate.[2]

These "small-scale" effects could result in the inappropriate use of LEFM methods and existing crack growth rate data resulting in an unconservative estimate of damage tolerance life.

Path Forward

Additional understanding will be required to establish limitations on the use of LEFM-based analysis and test methods for elastically responding COPV liners. This effort will require a better understanding of localized strain fields and microstructural considerations for applicable combinations of material, material processing, autofrettage and subsequent response characteristics, NDE method, and crack depth for each aspect ratio. Evaluation of these parameters and their relative importance to damage tolerance life would allow guidelines for the appropriate use of LEFM for thin liners.

Small-scale effects are not limited only to elastically responding liners. For COPVs with far-field plastic response, coupon or vessel testing is required per S-081A. Such tests may be adequate to address small scale effects by test if the test captures the effects of plasticity and microstructure in the remaining ligament; however, test methods and guidance for ensuring that worst-case conditions were present during coupon or full-scale tests would need to be developed.

The NESC will be developing specific guidelines for damage tolerance life analysis and test that addresses crack growth in these small uncracked ligaments that include localized plasticity and microstructure effects. This may result in the need for additional qualification tests to quantify crack growth in flight COPVs with thin liners.

References

1. ANSI/AIAA S-081A-2006, Space Systems-Composite Overwrapped Pressure Vessels (COPVs), American Institute of Aeronautics and Astronautics, VA.

2. ASTM Standard E647-15, Standard Test Method for Measurement of Fatigue Crack Growth Rates, ASTM International, West Conshohocken, PA.

For information contact the NESC at www.nesc.nasa.gov